Grasping and Manipulation Performance Measures and Benchmarking

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Agenda

• Overview of NIST Benchmarking work
  – Grasping and Manipulation (elemental level)
  – Robotic Assembly (functional/task level)

• Participant discussion of related work

• Formulation of a unified effort
NIST Goals

• Develop metrics, test methods and artifacts with example datasets to characterize the performance of grasping and manipulation with emphasis on deployment for manufacturing tasks.

• Provide the robotics community with unbiased measurement methods for both elemental characteristics and function-level performance capabilities.

• Short Term: Provide researchers and developers insight for improving their hardware and software designs

• Long Term: Used to develop specifications that will help match capabilities to end-user manufacturing needs
NIST Testbed

- Hands/Grippers
  - SCHUNK Dexterous Hand II
  - ROBOTIQ 3-Finger Gripper
  - Wonik Robotics Allegro Hand
  - Empire Robotics VERSABALL Gripper
  - Soft Robotics Inc.
  - Conventional parallel grippers

- Tactile Sensors
  - Syntouch BioTac, BioTac SP, & Numatac
  - OptoForce 3D Force sensors
  - ATI Industrial Automation Nano17 F/T transducers
  - Weiss Robotics Tactile sensors

- Arms
  - KUKA LWR 4+
  - Universal Robots UR5, UR10
  - ABB YuMi
  - Rethink Robotics Baxter
## Elemental Test Methods

<table>
<thead>
<tr>
<th>Test Method</th>
<th>Measurement Instrument</th>
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<tbody>
<tr>
<td>Finger Strength</td>
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<tr>
<td>Touch Sensitivity</td>
<td></td>
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<tr>
<td>Finger Force Tracking</td>
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<td>Force Calibration</td>
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<tr>
<td>Grasp Strength</td>
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<td>Slip Resistance</td>
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<td>Grasp Efficiency</td>
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<td>Cycle Time</td>
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<tr>
<td>In-Hand Manipulation</td>
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<tr>
<td>Object Pose Estimation</td>
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[http://www.nist.gov/el/isd/grasp.cfm](http://www.nist.gov/el/isd/grasp.cfm)
Touch Sensitivity

- **What:** A measure of the smallest, self-registered contact force exerted by a robotic finger on an object
- **How:** Measure maximum impact force at full finger extension at various joint speeds
- **Why:** Force dependent on speed, force maximized at full extension, minimize disturbance during object acquisition
Grasp Strength

- **What:** The maximum force a robotic hand can impose on an object
- **How:** Artifact with intrinsic force sensing
- **Why:** Estimate payload
In-Hand Manipulation

- **What**: Measure of a robotic hand’s ability to control the pose of an object
- **How**: MoCap system and objects with optical targets
- **Why**: Quantifies range-of-motion, frequency response, controller accuracy and repeatability, useful for functional-level tasks
Functional Performance Testing

- Quantify performance of a robotic system completing a task
- Tests target assembly operations: pick-place, insertion, fastening, meshing, wire harnessing, pulley belt routing
- Whole system-system testing
- Component testing

Test Design

- Assembly Operations
- Design for Assembly (DFA)
  - Human performance factor analysis
  - Parameterizes objects
  - Handling times
  - Insertion times
- Guide design space
- Direct human comparison

Performance Metrics

- **Modes**
  - Disassembly
  - Assembly
- **Primary metrics**
  - Speed $\rightarrow$ completion time
  - Reliability $\rightarrow$ probability of success
- **Granularity**
  - Per-part/operation
  - Whole board
Data Analytics

- Ordinal or Attribute Data
  - Detecting statistical difference in datasets – Kolmogorov-Conover
  - Check for differences as a whole or on a per rank basis
  - Primary performance measure: probability of success (PS)
- Continuous Data
  - Detecting statistical difference in datasets – Kolmogorov-Smirnov
  - Check for differences between sample means and variances
  - If no detectable differences, difference exists somewhere else (skewness, kurtosis)
- Matlab, R

http://www.nist.gov/el/isd/software.cfm
Example Peg-in-Hole

- Functional test method to measure the performance of robot systems at basic insertions
- Triangular design facilitates cyclical testing
- Peg-hole parameters, spacing based on human data

## Example Peg-in-Hole

### Robotic System

<table>
<thead>
<tr>
<th>Robotic System</th>
<th>Correlation</th>
<th>KS</th>
<th>$\mu$ (s)</th>
<th>$\sigma^2$ (s)</th>
<th>PS (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>System 1</td>
<td>0.01</td>
<td></td>
<td>18.31</td>
<td>107.3</td>
<td>87.6</td>
</tr>
<tr>
<td>System 2 Spiral</td>
<td>0.07</td>
<td>*</td>
<td>37.13*</td>
<td>399.6*</td>
<td>95.2</td>
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<tr>
<td>System 2 Random</td>
<td>-0.01</td>
<td>*</td>
<td>15.62</td>
<td>417.72</td>
<td>95.2</td>
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<tr>
<td>System 2 Quasi-Random</td>
<td>-0.11</td>
<td>*</td>
<td>8.2*</td>
<td>50.25*</td>
<td>95.2</td>
</tr>
</tbody>
</table>

*Indicates statistical significance in comparison with System 1.
Task Boards

• Series of themed boards
• Each instance focuses on particular assembly facets
• Design with reference to DFA
• Low-cost, internationally replicable
• Real components

Task Board #1

Concepts
Task Board #1

- Focuses simple insertions, nut threading, gear meshing, plug connections
- Design intersection
  - Spans DFA tables
  - Real components
  - Low-cost
  - Internationally replicable
- IROS 2017 competition
- Distribution
Documentation

• Grasping and Manipulation

• Robotic Assembly

• Working Publications – *(NIST Special Publication Format)*:
  Test method document – Performance Metrics and Test Methods for Robotic Hands
Publications


Competitions

• Mechanism for introducing benchmarking concepts to the research community in a competitive environment
• IROS 2016 household tasks with some manufacturing tasks introduced
• IROS 2017 dedicated manufacturing track
• World Robot Summit (WRS) Industrial Robotics 2018
• IROS 2019 - TBD
• WRS Industrial Robotics 2020
• European Robotics League
IROS 2017

• Robotic Grasping and Manipulation Competition: Manufacturing Track

WRS 2018

• WRS 2018 World Robot Challenge (WRC) Industrial Robotics Category
Related Work

• Yale-CMU-Berkley (YCB) Object Benchmarks for Robotic Manipulation
• Advanced Robotics for Manufacturing (ARM) Institute
• Berkeley led open discussion of robot grasping benchmarks, protocols and metrics
• UMass Lowell – NERVE Center
• Other?
Formulation of Unified Effort

• Propose unifying efforts with regular meetings under IEEE RHGM TC

• Periodic NIST hosted online
  – What is an appropriate frequency?
  – Sub-focus areas/sub-working groups could meet independently

• Yearly face-to-face at an IEEE robotics conference

• Consensus on tests, metrics, analyses will facilitate benchmarking

• Working publications as precursors to standards efforts

• Competitions